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DISPERSION ANALYSIS AND LINEAR ERROR ANALYSIS CAPABILITIES OF THE SPACE VEHICLE DYNAMICS SIMULATION PROGRAM

MISSION PLANNING, MISSION ANALYSIS AND SOFTWARE FORMULATION

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1.0 INTRODUCTION

Previous error analyses conducted by the Guidance and Dynamics Branch (GDB) of NASA have used the Guidance Analysis Program (GAP) as the trajectory simulation tool. Current plans are to conduct all future error analyses using the Space Vehicle Dynamics Simulation (SVDS) program. A study has been conducted to compare the Inertial Measurement Unit (IMU) error simulations of the two programs. This paper presents results of the GAP/SVDS comparison and defines problem areas encountered while attempting to simulate IMU errors, vehicle performance uncertainties and environmental uncertainties using SVDS. An evaluation of the SVDS Linear Error Analysis (LEA) capability is also included.

2.0 DISCUSSION

2.1 GAP/SVDS Comparison for IMU Error Sources

To evaluate an IMU simulation, the effects of guidance/navigation interfacing should be considered. The Mathematical Physics Branch (MPB), Software Development Branch (SDB) and GDB previously compared SVDS and Navigation Analysis Program (NAP) simulations for IMU errors. (See Reference 1.) However, the NAP and SVDS comparison was made at trajectory times prior to Solid Rocket Booster (SRB) staging. The effects of SVDS program phasing and guidance/navigation interfacing were not considered. This GAP/SVDS comparison considers both of these effects by making comparisons of trajectory data at main engine cutoff (MECO).

2.1.1 Selection of Nominal Trajectory and IMU Error Source Magnitudes

The last error analysis conducted by GDB was in June 1974. The trajectory used as a basis for the IMU error analysis was a Baseline Reference Mission 3A Abort Once Around (AOA) boost profile. In order to obtain comparable trajectory data from the IMU error sources, an SVDS simulation was developed to match this GAP nominal trajectory. A list of some key trajectory parameters of the GAP nominal trajectory and the SVDS trajectory is given in Table I. The table contains a comparison of the GAP and SVDS conditions at main engine cutoff (MECO). The trajectory differences at MECO are insignificant indicating that the GAP and SVDS trajectories compare closely enough for use in this analysis. The indicated SVDS trajectory is used as the basis for the SVDS IMU error analysis.

IMU error sources as defined in the last GDB error analysis were selected for use in this study. These values may not be the most recent evaluation of the uncertainties but were selected to obtain valid comparison data. Table II contains the error sources and their 3-sigma uncertainties in both GAP and SVDS input units. The SVDS simulations use the 3-sigma uncertainties for the error sources.

2.1.2 Trajectory Data Comparison

Table III contains the GAP/SVDS trajectory comparison data. Data are presented for deviations in position and velocity at MECO due

to each IMU error source simulation. The deviations are a result of 3-sigma uncertaintines and are computed as

$$\Delta = (\text{actual perturbed state vector component at MECO}) - (\text{nominal state vector component at MECO})$$

and are in an Earth-Centered Inertial (ECI) coordinate system. For each error source, deviations from the nominal are presented for both GAP and SVDS simulations. GAP data is the first line of state vector deviations for each error source and the SVDS deviations are presented in parentheses.

Examination of the trajectory deviation data reveals the following differences in GAP and SVDS simulations:

a. For some error sources, absolute value of the deviation in each state vector component is approximately the same but there is a difference in the signs of the deviations.

b. For some error sources, a difference exists in the definition of spin axis and output axis components.

c. For some error sources, the comparison between GAP and SVDS deviations show a large percentage variation in Z component of velocity.

An effort was undertaken to investigate these differences.

2.1.2.1 Sign Differences in GAP and SVDS Deviations

Examination of the programming code for GAP and SVDS reveals that sign differences exist in how the programs model some of the IMU error sources. The modeling differerces are reflected by corresponding trajectory deviations having similar magnitudes but opposite signs. The modeling differences result from the fact that the IMU model simulated by GAP is defined according to the conventions established for the Apollo project while the SVDS IMU model is consistent with current IMU definitions established by MPB (Reference 1). The following error sources are modeled with different sign conventions in GAP and SVDS and the differences are indicated by the deviation data in Table III:

a. free gyro drift bias (Z IMU error)
b. gyro spin axis acceleration sensitive drift (X and Y IMU errors)
c. gyro output axis acceleration sensitive drift (Z IMU error)
d. accelerometer input axis misalignment toward the output axis (X and Z IMU errors)
e. accelerometer input axis misalignment toward the spin axis (Y component).

2.1.2.2 Axis Definition Differences

An additional difference between GAP and SVDS exist in their definitions of spin axis and output axis for some of the error sources. The program definitions of spin axis and output axis are reversed when considering some components of IMU accelerometer input

axis misalignment and gyro acceleration sensitive drift. In determining how sensed velocity is to be perturbed for the Y component of the IMU error source (accelerometer input axis misalignment), GAP perturbes the Y component of sensed velocity by

a. $V_Y = V_Y + V_X$* (error source magnitude)

for misalignment toward spin axis and by

b. $V_Y = V_Y + V_Z$* (error source magnitude)

for misalignment toward output axis. The SVDS simulation models the spin axis and output axis oppositely. Equation (a) is used for perturbed sensed velocity for output axis and equation (b) is for spin axis in SVDS. GDB concurs with the MPB (SVDS) convention for these error sources. The GAP/SVDS comparison data of Table III is arranged to the GAP definitions for uniformity of comparison.

Similarly, for gyro acceleration sensitive drift (Z component of the IMU error), GAP models the perturbed sensed velocity X and Y components as

a_1. $V_X = V_X + V_Y^2$* (error source magnitude)

a_2. $V_Y = V_Y + V_X V_Y$* (error source magnitude)

for spin axis and as

$$b_1 \cdot V_X = V_X + V_X V_Y^* \text{ (error source magnitude)}$$

$$b_2 \cdot V_Y = V_Y + V_Y^{2*} \text{ (error source magnitude)}$$

for output axis. The SVDS simulation models the spin axis and output axis oppositely. Equations (a_1) and (a_2) are used for output axis and equations (b_1) and (b_2) are used for spin axis when considering the Z component of IMU error in gyro acceleration sensitive drift. Table III is arranged according to the GAP definitions for this error source for uniformity of comparison.

2.1.2.3 Z Velocity Deviation Differences

After making allowances for the previously discussed sign and axis definition differences, examination of the GAP and SVDS-generated state vector deviations of Table III shows that the only state vector component for which large percentage variations exist between GAP and SVDS is in the Z component of velocity for some of the error sources (e.g. gyro drift bias or accelerometer bias).

MECO conditions were investigated to see if the variation is a result of a variable MECO time or the inaccuracy of the cutoff velocity magnitudes. Neither of these proved to be the case. All of the problem cases had accurate cutoff times and comparable MECO velocities.

To determine which set of Z velocity deviations is more plausible (GAP or SVDS), an attempt was made to correlate velocity

deviations at MECO and position deviations. Consider the state vector deviations given in Table III for gyro input axis acceleration sensitive drift. Assuming that the X and Y components of velocity deviation are constant from liftoff to MECO in the sample case, it may be observed that a 2.5 ft/sec velocity deviation in X projects into a 460 ft deviation in position. Similarly, a -.04 ft/sec Y velocity deviation results in a -7 ft deviation at MECO. (See Table III.) Determining a ratio of position error to velocity error yields

$$\frac{\text{X position}}{\text{X velocity}} = \frac{\text{Y position}}{\text{Y velocity}} \approx 180 \frac{\text{ft}}{\text{ft/sec}}$$

for the indicated error source. Now consider the Z velocity deviation. Using the GAP value and the indicated position to velocity ratio yields

$$\text{Z position} = 180 \frac{\text{ft}}{\text{ft/sec}} * -.2 \frac{\text{ft}}{\text{sec}} = -36 \text{ ft.}$$

Using SVDS values yields

$$\text{Z position} = 180 \frac{\text{ft}}{\text{ft/sec}} * -.7 \frac{\text{ft}}{\text{sec}} = -126 \text{ ft.}$$

The actual position deviations for the error source are -127 feet in GAP and -123 feet in SVDS. The Z velocity and resulting position deviations show better correlation to the X and Y components in the SVDS. Similar results may be obtained for other sources.

The programming code of GAP and SVDS were examined to resolve the Z velocity deviation differences. No errors were found in either

program. The lack of comparison between GAP and SVDS for this velocity component remains an unresolved problem. However, since the magnitude of the Z component of velocity deviations are small and since the SVDS values appear to be acceptable, no further investigation of this discrepancy was attempted.

2.1.3 Conclusions

State vector deviations resulting from SVDS simulation of IMU errors are comparable to the deviations resulting from GAP simulations. SVDS may now be used as a simulation tool for generating an IMU error analysis. The sign and axis differences existing between GAP and SVDS present no problem since MPB has confirmed the IMU model within SVDS. (See Reference 1.)

2.2 Checkout of SVDS Dispersion Analysis Capability

Besides simulating IMU errors, SVDS must be able to simulate vehicle performance, aerodynamic and environmental uncertainties if it is to be an effective dispersion analysis tool. To checkout SVDS capabilities, trajectory simulations were developed using 3-sigma uncertainties in each of the following:

a. vehicle vacuum thrust, specific impulse and propellant loading for both the SRB and main engines.

b. inert weight for the SRB and external tank and orbiter

c. axial force coefficient and base drag

d. Vandenberg hot and cold atmospheres.

The resulting MECO insertion weight deviations were comparable to previous GDB dispersion analysis results. A GAP/SVDS comparison of trajectory and weight dispersions is not made in this report because:

a. since the last GAP error analysis was conducted, new SRB perturbation techniques have been defined (Reference 2).

b. nominal SVDS programming logic has previously been checked.

2.2.1 Problems Encountered in SVDS Dispersion Analysis Simulations

The following SVDS problems are encountered when attempting dispersion simulations:

a. stacked cases (multiple trajectory simulations in one job submittal) result in overflow of allotted tabular input capability.

b. Vandenberg hot and cold atmosphere models do not execute.

Simulation of SRB thrust and specific impulse uncertainties require input of several sets of tabular data (SVDS input parameter TABLE). When attempting stacked cases for these simulations, overflow of the TABLE length is encountered. According to SVDS documentation, input tabular data is overlayed for stacked cases. The overflow of TABLE encountered for these cases indicates that in multiple

SVDS cases, tabular data is added in series not overlayed. Software Development Branch (SDB) was notified of the problem and indicates that the program alterations required to fix this problem would be included in the next SVDS update; however, they do not plan to attempt any checkout cases to verify the program modifications.

It should be noted that one program fix for this problem is to increase the dimension of allowable tabular inputs. This was not attempted in this study because of a lack of unused core on the current version of SVDS.

Attempts were made to simulate the Vandenberg hot and cold atmospheres as environmental uncertainties. Neither of these SVDS options will execute. The programming code exist for modeling the uncertainties but program modifications are necessary before SVDS will execute the options. A discrepancy report (Reference 3) has been submitted to SDB indicating this problem.

2.2.2 Conclusions of SVDS Dispersion Analysis Checkout

To efficiently conduct a dispersion analysis, the trajectory simulations for the uncertainties should be generated in a limited number of computer job submittals. SVDS cannot currently handle the required stacked cases which involve tabular data. Atmospheric uncertainties are also not executable on SVDS. SDB support is required in both these areas before a complete dispersion analysis can be conducted.

2.3 Checkout of Linear Error Analysis (LEA) Capability

The current directive from GDB indicates that dispersion analyses will be conducted as single error source cases. A LEA technique will be used to statistically correlate trajectory deviations for all uncertainties by developing covariance matrices at various flight events. As part of this study, an effort was undertaken to exercise and verify the LEA capability in conjunction with SVDS. The study was hampered by the lack of good documentation defining techniques for use of the LEA processor.

2.3.1 LEA Procedures

The LEA option of SVDS determines the following output data:

a. trajectory parameter deviations defined in a local horizontal coordinate system (LHS)

b. the root-sum-square (RSS) of the trajectory parameter deviations

c. a covariance matrix relating all of the error sources.

To exercise the LEA processor, SVDS trajectories must first be simulated. For the LEA processor to generate covariance data and RSS data for the desired trajectory parameters at the desired flight events, the following procedure is required in developing the SVDS trajectories:

a. determine the state vector components and performance parameters for which LEA results are desired

b. determine the flight events at which LEA results are desired

c. generate a nominal SVDS trajectory and trajectories for each of the error sources using the 3-sigma uncertainty

d. create a tape containing the perturbed trajectory parameters at each of the required flight events for all the SVDS trajectories.

The SVDS-generated tape should contain a file for each SVDS trajectory (a nominal followed by the perturbed trajectories). Each file of the tape should contain records for only the flight events required for the LEA. Each record should contain the trajectory parameters to be used in the LEA. Schematically the tape may be represented as:

File 1 (Nominal)

Record 1 Trajectory parameter data

Record 2 Trajectory parameter data

.
.
.

End of file

File 2 (Perturbed Case)

Record 1 Trajectory parameter data

Record 2 Trajectory parameter data

.
.
.

End of file

File i (Perturbed Case)

.
.
.

To generate a SVDS tape written as depicted, the following SVDS inputs should be used:

a. PLOT = The desired trajectory parameter data

b. IPLOT = 10000 in those SVDS program phases which terminate at a flight event specified for LEA

IPLOT = 0 in all other SVDS program phases

c. MCPT = 1

It should be noted that the SVDS tape write and LEA tape read units currently do not match if default values are used in both processors. SVDS assigns the tape write to unit F while the LEA reads unit D. This poses no problem if the SVDS trajectory simulations and LEA processor are submitted separately.
The tape assign control cards (ASG = unit i) must be identified as unit F (in SVDS) and unit D (for LEA processor). If the SVDS trajectory simulations and LEA processor are run in one job submittal, the output and input units must be matched. This can be controlled by inputting IPUNIT = 4 in SVDS (forces output onto unit D) <u>or</u> setting JUNIT = 8 in LEA inputs (forces reading of unit F). The tape assign cards should be input accordingly.

As previously indicated, the LEA processor uses trajectory dispersions developed using 3-sigma uncertainties in the error sources. The LEA processor reads the SVDS state vectors of the nominal

trajectory (developed in an earth-centered inertial coordinate system) and forms a LHS based on the nominal data. The LHS coordinate system is defined by:

$$\hat{U} = \overline{R}/|\overline{R}|$$

$$\hat{V} = (\overline{R} \times \overline{V} \times \overline{R})/|\overline{R} \times \overline{V} \times \overline{R}|$$

$$\hat{W} = U \times V$$

where $\overline{R}$ and $\overline{V}$ are the radius and velocity vectors of the nominal trajectory at the trajectory time for which the LEA exercise is specified. The LEA processor then rotates the state vector deviations of the perturbed cases into the LHS and combines the deviations by a root-sum-square (RSS) process. The resulting RSS is based on 3-sigma uncertainties. The LEA processor then forms a covariance matrix indicative of all the simulated error sources. The covariance matrix is based on 1-sigma level of confidence for the error sources.

2.3.2 LEA Difficulties Encountered

Other than the lack of documentation defining LEA procedures, the following problems were encountered in using the SVDS LEA processor:

a. the LEA processor can read only one input tape

b. the processor is limited to reading 500 files of data.

The limitation of one input data tape for LEA seems to imply that the nominal and all error source trajectory simulations must be run in one SVDS job submittal. The UNIVAC system does not allow

reading and then writing on the same tape, so it is not possible to create a nominal trajectory tape in one job submittal and subsequently add data files for the error source cases as they are generated in other job submittals. However, investigation of UNIVAC tape capabilities reveals that several existing tapes can be combined by executing a tape processor called MATCH. This allows for dividing the SVDS trajectory simulations into several small jobs (each creating a tape of dispersed trajectory parameters) and combining the tapes for LEA purposes. The control card setup for this operation is

XQT MATCH
DUP $unit_1$, $unit_C$
TEF $unit_C$
DUP $unit_2$, $unit_C$
TEF $unit_C$
.
.
.
DUP $unit_i$, $unit_C$
TEF $unit_C$

where $unit_i$, i = 1, 2, . . . are the SVDS tapes with the dispersion data from the error source cases and $unit_C$ is the tape unit onto which the files are being combined. The TEF directive is required to separate the files of $unit_C$ by an end of file (EOF).

The process can be used to delete a file if a series of SVDS simulations were generated and one case was found to be in error. The MATCH directive will allow for submittal of several short SVDS simulations rather than one large multi-case simulation requiring a one hour run estimate.

As previously indicated, when generating the SVDS trajectory simulations tape records should be written only at the flight events for which LEA processing is desired. This restriction is imposed by the limitation of storage location for the LEA processor. The processor is currently limited to 500 storage points of trajectory data. That is, the total number of the event and time slices for all perturbation cases and the nominal must not exceed 500:

$$(\Sigma \text{Events} + \Sigma \text{Time slices})^* \\ (\text{Perturbation cases} + 1) \leq 500.$$

This limitation may not be realistic for dispersion analyses of trajectories such as reference mission 3A where an abort once around is considered.

2.3.3 Conclusions of LEA Investigation

As part of this study, the LEA computations were verified by hand calculating the following:

a. the rotation matrix used to rotate ECI state vector deviations into the LHS.

b. the RSS of the state vector deviations.

c. the covariance matrix at randomly selected points.

The hand calculations match the computer determined data.

The major difficulty encountered while attempting to execute the LEA processor was the lack of documentation defining input procedures and requirements. SDB indicates that updated LEA processor documentation is underway.

3.0 CONCLUSIONS

The SVDS program is now an adequate simulation tool for conducting error analyses of IMU errors. SVDS needs to be modified before a complete dispersion analysis can be conducted. In particular, SVDS atmospheric perturbation capability needs to be corrected, core requirements need to be reduced, and the problems of stacking cases which require tabular input data need to be resolved. The LEA processor is executing properly but better documentation is required to make it an effective tool.

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TABLE I

NOMINAL COMPARISON TRAJECTORY

EVENT	TIME - SEC	WEIGHT - LB	THRUST - LB	RADIUS - FT	INERTIAL FLIGHT PATH ANGLE - DEG	VELOCITY - FT/SEC	GEOCENTRIC LATITUDE - RADIAN	LONGITUDE - RADIAN
OTP								
LIFTOFF	0.00	4159925	6264384	20903081	0.00	1255.2	34.56	-120.62
BEGIN PITCH-OVER	6.00	4015735	6269554	20903385	4.69	1259.3	34.56	-120.62
BEGIN GRAVITY TURN	15.00	3775586	6307285	20905371	13.48	1283.4	34.56	-120.62
SOLID ROCKET BOOSTER CUT-OFF	126.46	1714361	1540356	21046785	25.26	4558.8	34.14	-120.79
SOLID ROCKET BOOSTER SEPARATION	126.46	1405863	1536356	21046785	25.26	4558.8	34.14	-120.79
FAIL ONE MAIN ENG	258.86	958841	1040188	21206708	3.54	8975.6	31.89	-121.66
MAIN ENGINE CUTOFF	560.30	285332	856372	21229680	0.75	25507.5	19.75	-126.29
SVDS								
LIFTOFF	0.00	4159925	6264384	20903080	0.00	1255.2	34.57	-120.62
BEGIN PITCH-OVER	6.00	4015736	6269616	20903384	4.69	1259.3	34.57	-120.62
BEGIN GRAVITY TURN	16.00	3775528	6301979	20905368	13.47	1283.4	34.57	-120.62
SOLID ROCKET BOOSTER CUT-OFF	126.45	1714366	1540356	21046775	25.24	4563.1	34.14	-120.79
SOLID ROCKET BOOSTER SEPARATION	126.46	1405866	1536356	21046775	25.24	4563.1	34.14	-120.79
FAIL ONE MAIN ENG	258.36	958847	1010189	21207085	3.54	8985.2	31.89	-121.66
MAIN ENGINE CUTOFF	559.06	284846	849859	21229743	0.75	25507.5	19.80	-126.27
Δ = OTP - SVDS [illegible]	1.25	485	6513	-63	0.00	0.0	-.05	.02

TABLE II

IMU ERROR SOURCE DEFINITION

ERROR SOURCE	DISPERSION (3σ)	GAP INPUT VARIABLE	GAP INPUT UNITS	SVDS INPUT VARIABLE	SVDS INPUT UNITS
INITIAL PLATFORM MISALIGNMENT		PM (I)		PLTSIG (I)	
AZIMUTH	190 sec	I=1	.0528 deg	I=1	9.215E-4 rad
TILT, ROLL	63 sec	2,3	.01761 deg	2,3	3.0735E-4 rad
FREE GYRO BIAS	.0443 deg/hr	WD (I) I = 1,2,3	.0000123 deg/sec	GYBIAS (I) I = 1,2,3	2.147E-7 rad/sec
GYRO INPUT AXIS ACCELERATION SENSITIVE DRIFT	.075 deg/hr/g	ADIA (I) I = 1,2,3	6.474E-7 deg-sec/ft	GDSIG (I) I = 1,2,3	1.130E-8 rad-sec/ft
GYRO SPIN AXIS ACCELERATION DRIFT	.075 deg/hr/g	ADSRA (I) I = 1,2,3	6.474E-7 deg-sec/ft	GDSIG (I) I = 7,8,15	1.130E-8 rad-sec/ft
GYRO OUTPUT AXIS ACCELERATION SENSITIVE DRIFT	.0075 deg/hr/g	ADOA (I) I = 1,2,3	6.474E-8 deg-sec/ft	GDSIG (I) I = 13,14,9	1.130E-9 rad-sec/ft
ACCELEROMETER BIAS	149 μg	ABIAS (I) I = 1,2,3	4.824E-3 ft/sec^2	ACBIAS (I) I = 1,2,3	4.824E-3 ft/sec^2
ACCELEROMETER SCALE ERRORS FACTOR	120 ppm	ASF (I) I = 1,2,3	.00012	ACSSIG (I) I = 1,2,3	.00012
ACCELEROMETER INPUT AXIS MIS-ALIGNMENT		AM (I)		ACSSIG (I)	
- TOWARD OUTPUT AXIS	45.4 sec	I = 2,4,5	.0126 deg	I = 13,8,15	2.199E-4 rad
- TOWARD SPIN AXIS		1,3,5		7,14,9	

TABLE III

GAP/SVDS TRAJECTORY DATA COMPARISON

GAP	SVDS (b)	Deviations in Position - Feet (a) X	Y	Z	Deviations in Velocity - Feet/Second (a) X	Y	Z
INITIAL PLATFORM MISALIGNMENT							
PM (1)	PLTSIG (1)	5086.50 (5069.54)	-50.00 (-34.63)	-1371.00 (-1332.70)	21.854 (21.512)	-.300 (-.346)	-5.925 (-5.828)
PM (2)	PLTSIG (2)	459.70 (424.59)	-899.00 (-942.35)	1817.70 (1679.00)	1.798 (1.760)	-5.008 (-4.737)	7.056 (6.932)
PM (3)	PLTSIG (3)	-1294.10 (-1291.20)	33.00 (35.33)	290.40 (289.80)	-2.899 (-2.979)	.201 (.211)	.550 (.567)
FREE GYRO DRIFT BIAS							
WD (1)	GYBIAS (1)	266.10 (269.13)	-5.00 (-3.44)	-74.50 (-73.10)	1.777 (1.711)	-.014 (-.027)	.002 (-.472)
WD (2)	GYBIAS (2)	53.20 (59.57)	-172.00 (-180.01)	249.30 (224.40)	.358 (.342)	-1.434 (-1.312)	1.885 (1.339)
WD (3)	GYBIAS (3) (c)	115.70 (-114.82)	-9.00 (10.25)	-21.50 (21.40)	.331 (-.360)	-.045 (.055)	.448 (.047)
GYRO INPUT AXIS ACCELERATION SENSITIVE DRIFT							
ADIA (1)	GDSIG (1)	457.60 (456.89)	-7.00 (-4.67)	-126.60 (-123.00)	2.501 (2.435)	-.036 (-.044)	-.193 (-.669)
ADIA (2)	GDSIG (2)	2.10 (2.98)	-8.00 (-8.01)	8.30 (7.60)	.018 (.019)	-.079 (-.083)	.562 (.069)
ADIA (3)	GDSIG (3)	-186.50 (-183.65)	16.00 (19.37)	32.40 (31.40)	-.551 (-.606)	.107 (.108)	.549 (.066)

Note:
(a) Deviations are computed as Δ= (actual perturbed state vector component at MECO)-(nominal state vector component at MECO).
(b) SVDS trajectory deviations are presented in parenthesis.
(c) Sign differences in the deviations are explained in paragraph 2.1.2.1.

TABLE III (continued)

GAP/SVDS TRAJECTORY DATA COMPARISON

ERROR SOURCE	Deviations in Position - Feet (a)			Deviations in Velocity - Feet/Second (a)		
	Y	X	Z	X	Y	Z
GYRO SPIN AXIS ACCELERATION SENSITIVE DRIFT						
ADSRA (1) GDSIG (7) (c)	-10.30 (11.29)	.00 (-.79)	3.00 (-3.20)	-.112 (.102)	.003 (-.002)	.524 (-.029)
ADSRA (2) GDSIG (8) (c)	-113.80 (103.97)	326.00 (-344.07)	-448.80 (401.10)	-.706 (.672)	2.981 (-2.746)	-2.242 (2.626)
ADSRA (3) GDSIG (15)	-2.50 (-.66)	.00 (.76)	.40 (1.00)	-.001 (-.008)	.016 (.002)	.438 (.002)
GYRO OUTPUT AXIS ACCELERATION SENSITIVE DRIFT						
ADOA (1) GDSIG (13)	49.40 (50.33)	-2.00 (-.02)	-13.90 (-13.10)	.370 (.348)	-.003 (-.005)	.392 (-.094)
ADOA (2) GDSIG (14)	11.30 (12.11)	-28.00 (-29.21)	44.50 (39.00)	.055 (.051)	-.198 (-.186)	.706 (.204)
ADOA (3) GDSIG (9) (c)	22.90 (-21.82)	-2.00 (2.25)	-4.60 (4.20)	.062 (-.068)	-.006 (.002)	.483 (.013)
ACCELEROMETER BIAS						
ABIAS (1) ACBIAS (1)	-132.10 (-119.51)	642.00 (665.58)	-508.80 (-453.00)	-.453 (-.448)	2.580 (2.513)	-1.194 (-1.670)
ABIAS (2) ACBIAS (2)	708.30 (705.40)	6.00 (11.07)	-169.40 (-164.90)	2.362 (2.365)	-.004 (-.002)	-.079 (-.375)
ABIAS (3) ACBIAS (3)	130.40 (129.58)	426.00 (428.92)	545.10 (550.00)	.457 (.451)	1.585 (1.526)	2.405 (1.905)

Note: (a) Deviations are computed as Δ= (actual perturbed state vector component at MECO)-(nominal state vector component at MECO).

(b) SVDS trajectory deviations are presented in parenthesis.

(c) Sign differences in the deviations are explained in paragraph 2.1.2.1.

TABLE III (continued)

GAP/SVDS TRAJECTORY DATA COMPARISON

ERROR SOURCE		Deviations in Position - Feet (a)			Deviations in Velocity - Feet/Second (a)		
		X	Y	Z	X	Y	Z
ACCELEROMETER SCALE FACTOR ERRORS							
ASF (1)	ACSSIG (1)	-98.50 (-93.63)	469.00 (480.15)	-378.80 (-356.00)	-.249 (-.250)	1.452 (1.438)	-.912 (-.918)
ASF (2)	ACSSIG (2)	18.30 (17.03)	.00 (.21)	-3.80 (-3.50)	.091 (.090)	-.003 (-.004)	-.019 (-.020)
ASF (3)	ACSSIG (3)	159.50 (159.53)	462.00 (461.53)	669.10 (670.90)	.576 (.565)	1.664 (1.661)	2.383 (2.360)
ACCELEROMETER INPUT AXIS MISALIGNMENTS TOWARD - OUTPUT AXIS							
AM (2)	ACSSIG (13) (c)	223.20 (-178.07)	-1096.00 (1128.36)	859.70 (-745.50)	.946 (-.916)	-5.353 (5.163)	3.553 (-3.456)
AM (4)	ACSSIG (8)	1223.30 (1219.17)	13.00 (18.68)	-287.60 (-277.80)	5.248 (5.163)	.021 (-.004)	-1.276 (-1.249)
AM (6)	ACSSIG (15) (c)	-9.40 (8.29)	-26.00 (27.06)	-39.80 (41.00)	-.032 (.036)	-.107 (.092)	-.132 (.141)
- SPIN AXIS							
AM (1)	ACSSIG (7)	-4.80 (-3.40)	29.00 (31.43)	-18.30 (-14.70)	-.027 (-.029)	.149 (.147)	-.102 (-.102)
AM (3)	ACSSIG (14) (c)	-921.20 (917.90)	-5.00 (8.80)	225.90 (-221.50)	-2.051 (2.108)	-.007 (-.001)	.496 (-.507)
AM (5)	ACSSIG (9)	106.00 (106.05)	452.00 (455.53)	441.90 (447.80)	.342 (.340)	1.759 (1.717)	1.500 (1.503)

Note:

(a) Deviations are computed as Δ= (actual perturbed state vector component at MECO)-(nominal state vector component at MECO).

(b) SVDS trajectory deviations are presented in parenthesis.

(c) Sign differences in the deviations are explained in paragraph 2.1.2.1.

REFERENCES

1. NASA Memorandum FM82(74-328), "Space Vehicle Dynamics Simulation (SVDS) Navigation Block Verification", dated 15 November 1974.

2. NASA Memorandum FM73(74-202), "Shuttle Ascent Design Issues", dated 20 December 1974.

3. SVDS Discrepancy Report MDC-31, "Atmosphere Model", dated 11 March 1975.